The Coalition of Finance Ministers for Climate Action

The fiscal case for adaptation and improved sustainability analysis

Environmental Change Institute, University of Oxford

Mathias Weidinger and Nicola Ranger

A contribution to the 'Compendium of Practice from a Global Community of Ministries of Finance and Leading Organizations: Economic analysis and modeling tools to assist Ministries of Finance in driving green and resilient transitions'

Topic: Addressing the climate policy questions facing Ministries of Finance: the economic and fiscal impacts of adaptation and resilience

June 2025

Access the full Compendium at www.greenandresilienteconomics.org

Key messages

- Climate change should routinely be integrated with fiscal risk and debt sustainability analyses, including analyzing the benefits of adaptation for fiscal space, fiscal resilience, and sovereign credit ratings.
- Ministries of Finance can actively investigate how the cost of capital for sovereign financing instruments could be reduced through investment in adaptation, including appropriate disaster risk financing strategies and opportunities for labeled bonds and sustainability-linked sovereign finance.
- Ending counterproductive expenditure, including climate damaging subsidies, should become a priority for all stakeholders involved in planning and implementing climate-compatible public finance across the world.
- Furthermore, a case study shows that avoided costs in terms of reduced borrowing costs and lower probability of default by sovereigns could significantly outweigh the necessary initial investments in climate adaptation.

Background

Investment in resilient and sustainable infrastructure stimulates new jobs, trade, growth, and access to water, energy, education, and healthcare. A tremendous opportunity for inclusive pro-poor development, it can contribute to more than 92% of the UN Sustainable Development Goals (SDGs) targets (Thacker et al., 2021; UNEP, 2023). Still, new infrastructure investments of well over US$1 trillion per year are needed until 2040 to achieve the SDGs (High-Level Expert Group on Scaling up Sustainable Finance in Low- and Middle-Income Countries, 2024). The bulk of this finance (70%) is required for investments in emerging and developing economies (EMDEs), which not only are the focus of the human development agenda but also bear the brunt of climate change.

Climate-related disruptions to infrastructure already cost EMDEs an estimated US$390 billion per year (Hallegatte et al., 2020), and will almost certainly increase further in the coming decades unless climate mitigation and adaptation pick up significantly. "Business as usual" would significantly afflict the poorest, curtailing their incomes and access to basic services, and potentially setting back decades of progress on poverty alleviation (Weikmans, 2023; Dang et al., 2024). The costs of disruption to infrastructure assets can also strain fiscal budgets and reduce productivity, with knock-on effects for growth, investment, and poverty alleviation (Ranger et al., 2021). Making infrastructure resilient early on is particularly important, given the long lifespan of infrastructure and the locking-in of direct and indirect impacts for many decades to come (Hall et al., 2016).

Several authors (Thacker et al., 2021; UNEP, 2023; Hallegatte et al., 2019; Hall et al., 2019; Bassi et al., 2021; Rozenberg and Fay, 2019) have pointed to the significant fiscal benefits of investment in resilient and sustainable infrastructure, in terms both of reduced costs (e.g., of reconstruction, recovery, disruption to critical services, and taxation) and long-term macroeconomic trajectories (e.g. high employment and growth rates). The public sector plays multiple roles that are critical in this respect, e.g., financier, regulator, catalyst, and policymaker. This contribution focuses on the specific roles MoFs can play, in coordination with other stakeholders, to enable adaptation through targeted fiscal spending in adaptation-relevant infrastructure. These insights are discussed in greater detail in two recent reports by the University of Oxford, one commissioned by the UN Environment Programme as part of an ongoing collaboration on Sustainable Fiscal Policy (Ranger et al., 2025), the other supported by the UK Centre for Greening Finance and Investment and the Oxford Martin School (Bernhofen et al., 2024).

A false dichotomy

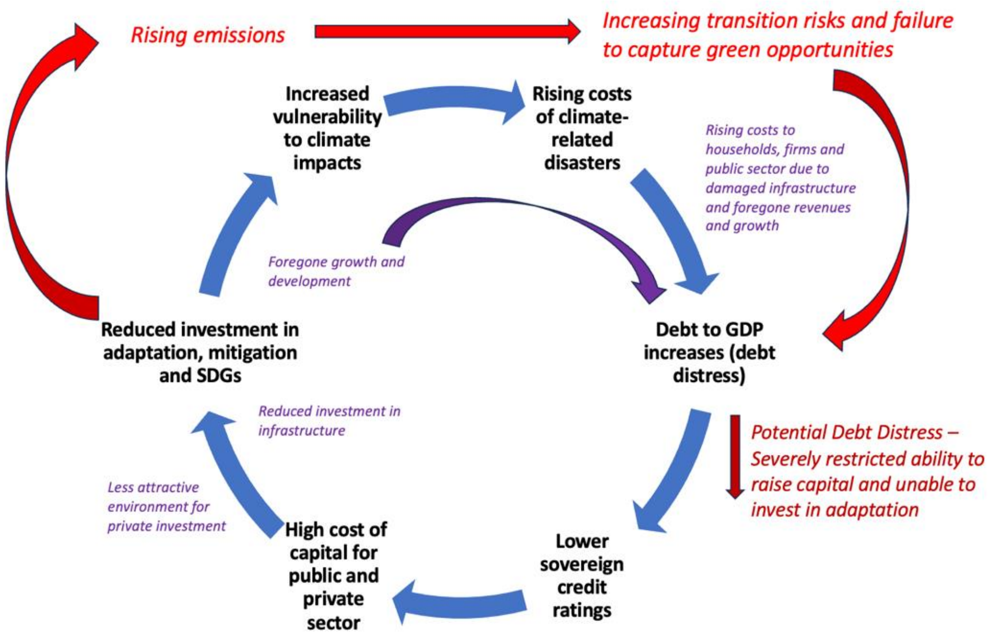
Despite the convincing fiscal case for investing in resilient and sustainable infrastructure, current debt sustainability analysis (DSA) frameworks build on the tacit assumption that there is a dichotomy between debt sustainability and adaptation investment. As a result, several countries note difficulties with investing in adaptation under current debt ceilings. This analysis provides countervailing evidence of sizable synergies between adaptation investment and debt sustainability. To make fiscal frameworks fit for the challenges of the 21st century requires a more thorough treatment of physical risks and adaptation within DSA, and an exploration of the potential to reduce the cost of capital in sovereign financing where this is linked to adaptation.

The adaptation investment trap

Consider the adaptation investment trap depicted in Figure 1. The blue cycle indicates how rising costs of climate-related disasters increase debt and in some cases lead to debt distress (Volz et al., 2020). This creates a poor investment environment and higher cost of capital for affected countries, which in turn constrains investment in climate adaptation. This leads to greater climate vulnerability and still higher losses from climate-related disasters, further exacerbating debt sustainability and further deteriorating the investment environment. The red arrows indicate an additional feedback loop, based on rising emissions leading to increased transition risks and a failure to capture green opportunities, that reinforces the vicious cycle.

To escape this trap, climate and adaptation spending should be incorporated into fiscal risk and debt sustainability analyses so that it counts as an investment in future sovereign finance ability rather than an unequivocal burden on the public budget. This is justified because investments in insurance and adaptation can help offset debt sustainability challenges in the medium term.

Figure 1. The adaptation investment trap



Source: Ranger et al., 2025 (authors' compilation, analogous to Ameli et al., 2021)

Case study

Recent estimates for Thailand—one of the countries most exposed to river flooding in the world — suggest that additional investments in building codes, infrastructure resilience, and insurance penetration could decrease the probability of sovereign default following a 1-in-500-year flood in 2050 by 3.5% relative to a high-emissions scenario (RCP 8.5). In terms of credit ratings, this is equivalent to the difference between a 1.5 and a 3.16 notch downgrade. For a 1-in-500-year tropical cyclone, the same investments would limit the downgrade to 0.86 rather than 1.3 notches. A similar analysis of an upper middle-income small island state yields similar results, indicating that hypothetical insurance could absorb up to 50% of losses from a 1-in-250-year fluvial flood event (Ranger et al., 2025).

Climate-sensitive Debt Sustainability Analysis

MoFs, World Bank and IMF staff commonly model the impact of shocks and stressors on debt sustainability using Debt Sustainability Analysis (DSA) and the Sovereign Risk and Debt Sustainability Framework (SRDSF) alongside the IMF-World Bank Debt Sustainability Framework for Low Income Countries (LIC DSF) (IMF, 2022a). There are several examples of climate change being incorporated into DSAs using these frameworks, for example, in Vanuatu and Timor-Leste (IMF, 2019, 2022b). SRDSF and LICDSF include two aspects of relevance to understanding climate risks: medium-term risk assessment to capture specific risks facing countries that are not fully captured, including natural disasters, and long-term risk assessment, which covers risks of debt-related stress that could materialize after five or more years.

One of four optional modules included in the SRDSF to help users analyze key issues that could drive debt-related risks well into the future deals with the "consequences of adaptation and mitigation investments to combat climate change" (IMF, 2022a). This scenario-based inclusion of climate change within the SRDSF (and the LIC DSF) toolkit is, however, simplistic and constructed based on the assumptions entered by users. Only a few of the transmission channels are captured in the standardized scenarios, and the inclusion of climate change's physical impacts is too narrow, not accounting for changes in climate risk over time or the potential for higher impact events. These challenges undermine the validity of DSAs.

Economic models matter

To be useful for DSAs, economic models need to capture the complex interactions between the economy, climate impacts, government budgets, adaptation, and mitigation investments. There are significant and well-known uncertainties in the projections of the effects of climate change on the macroeconomic variables utilized in DSAs, driven by the uncertainties in the trajectory of socioeconomic development globally and the resulting national and global emissions, as well as the response of the global climate, the impacts on natural, social and economic systems, and our societal responses to these (i.e. adaptation). A further source of uncertainty is the prediction of the interaction with the economy at micro- and macro-levels, and knock-on effects across the financial system and government fiscal balances (Ranger et al., 2022, 2023).

Integrated assessment models (IAMs), and aggregate ones in particular, present an incomplete picture of the impacts of climate change, even relative to other types of macroeconomic models (see Appendix) (Monasterolo et al., 2022). Several aspects, including extreme weather shocks (Stern 2016), biodiversity links (Dasgupta 2024), migration, crop yields, and social instabilities in exposed regions are missing, as is the potential for cascading and compounding risks or nonlinear effects (Hepburn and Farmer, 2020; Farmer et al., 2015). Thus, the current standard economic toolkit is not well-suited for analyzing the economic, fiscal, and financial impacts of climate change (Monasterolo et al., 2022; Johnson et al., 2021; Ranger et al., 2024; Volz and Ranger 2024; Battiston et al., 2021; Bressan et al., 2024).

From harmful subsidies to investments in prosperity

Despite the promise of fiscal win-wins from investing in adaptation, previous analyses show that current fiscal practices tend to be counterproductive, on balance. While a lot of public expenditure, such as subsidies for fossil fuels or agricultural production, actively deteriorate the climate and nature risk landscapes, only a small fraction of fiscal outlays aligns with adaptation and resilience goals (Spacey Martín and Ranger, n.d.; Sadler et al., 2024). This mismatch points to opportunities for leveraging existing standards and frameworks and highlights the potential of taxonomies in this respect (Spacey Martín et al., 2024; Marotta et al., 2023; Batten 2018). Resilience and nature must be further integrated within sustainable budgeting approaches, project procurement and appraisal, using approaches such as the one designed by University of Oxford and UNEP (2024).

A study published in 2023 provided "climate-smart" sovereign credit ratings for the first time, finding that over 50 countries could experience climate-induced downgrades as early as 2030. By 2100, nearly three-quarters of the analyzed countries would experience downgrades, with an average downgrade of 2.18 notches in a high-emission (RCP8.5) scenario (Klusak et al. 2023). Since the climate impacts in this study are based on derived relationships between temperature variability and GDP growth (Kahn et al., 2021), these estimates relate to economic impacts of climate change in aggregate but fall short of capturing the effects of extreme events (such as floods or tropical cyclones). This means that these estimates of sovereign climate credit risk may be underestimating the actual risk (Bernhofen et al, 2024).

An analysis of the fiscal impacts of earthquakes and floods and the benefits of adaptation infrastructure investments in a low-income African economy serves as an example of how DSA can be made more sensitive to physical climate risks, including from extreme events. After calibrating a dynamic general equilibrium model (Aligishiev et al., 2022, 2023) to match the country's macroeconomic profile, two main public infrastructure investment options are considered: standard and adaptation infrastructure; the latter is more expensive than its counterpart but has a lower depreciation rate and higher rate of return on investment (Marto et al, 2018; Melina and Santoro, 2021). For each option, it is assumed that the Government invests 1.0% of GDP into its respective infrastructure options for the first five years before the disaster occurs and uses the public domestic and external commercial debt to cover the fiscal gap.

The direct damages of earthquake and flood events (for, both, 1-in-10- and 1-in-1,000-year return periods) are estimated based on a fully probabilistic model that can estimate the economic impacts of climate risks to infrastructure (CDRI, 2023). When a disaster occurs, it affects the economy via three channels: destroying public infrastructure assets, destroying private assets, and reducing the total factor productivity. The results suggest that in the case of earthquakes between 0.2% and 2.8% of the total post-disaster public debt could be mitigated through adaptation infrastructure investment, and in the case of flooding between 0.2% and 0.4% could be mitigated. Considering only capture direct damages are captured and government investment in adaptation infrastructure is limited to 1% of GDP per year, estimates of the fiscal benefits are likely rather conservative (Ranger et al., 2025).

The Thailand case study (Bernhofen et al., 2024) was also extended using the same methodology, combining a flood risk and adaptation model, a macroeconomic model (Aligishiev et al., 2023), and a model of sovereign credit risk under climate change (Klusak et al., 2023). A 1-in-100-year event today would lead to GDP losses of nearly 3%, which could be linked to a single notch downgrade in Thailand's sovereign credit rating. In the future, the same probability event would lead to GDP losses of between 3.7% and 4.5%, resulting in a simulated two-notch downgrade. A two-notch downgrade would increase Thailand's probability of default by 4% and lead to increased interest payments of around US$1.9 billion a year. For a rare 1-in-1,000-year return period flood, Thailand's sovereign credit rating risks falling below the investment grade, with GDP losses exceeding 6.5%.

These sovereign rating impacts exceed the chronic impacts of climate change estimated by previous studies (see, for example, Klusak et al., 2023) and would likely be additional, resulting in amplified rating risks. This analysis demonstrates the critical importance of accounting for acute climate shocks and leads us to propose the use of probabilistic models and scenarios within sovereign credit risk. The same analysis also shows that additional adaptation investments can reduce average annual future losses from flooding by up to US$9.5 billion (a 64% decrease). They could also significantly reduce the losses of extreme events. Adaptation would lead to avoided losses of up to US$30 billion and US$48 billion for a 1-in-100-year and a 1-in-1,000-year flood, respectively. This underpins our case for actively considering climate risks, including those from extreme events, in DSA frameworks, and reframing fiscal spending on climate adaptation as profitable investments. Debt limits should, therefore, differentiate them from other outlays that do not exhibit the same long-term fiscal benefits.

Conclusion

This contribution identified several priorities that are relevant for MoFs in different contexts and may prove transformative in the transition toward more resilience and sustainable growth in EMDEs. First, no additional harm should come from fiscal policies, and thus, harmful subsidies should be phased out as a matter of priority. Second, MoFs can effectively lead efforts to address the false dichotomy that pitches adaptation-spending against fiscal prudence. Thereby, they would ensure that their countries stay clear of the adaptation investment trap.

MoFs are in a unique position to coordinate a structural shift in the norms surrounding DSA and should make use of their influence to ensure that future standards take climate mitigation and adaptation, as well as social equity and inclusion, into consideration. Quantifying what a country is (or is not) doing to adapt to climate change and reflecting this in a future stress test of key metrics could help incentivize more investment toward adaptation by showing the investment case for adaptation pathways over time. Initial findings indicate that avoided costs (in terms of reduced borrowing costs and lower probability of default) could significantly outweigh the initial adaptation investments (Bernhofen et al., 2024).

Indeed, not including avoided costs, and not fully representing the risks, could create a disincentive for adaptation investment. Information on how countries' risks change with climate change, and what this means for their debt and cost of capital, helps MoFs to chart a roadmap for investment over time to manage risks effectively. The examples briefly described here indicate how this can be achieved, even using the relatively limited toolkit currently available to practitioners. Of course, MoFs can also play an active role in the funding, development, and popularization of new tools that are better suited to integrate DSA with cross-cutting issues such as climate risk and resilience.

This material has been produced with support from the Climate Compatible Growth (CCG) program, which brings together leading research organizations and is funded by UK aid from the UK government.

References

Aligishiev, Z., Bellon, M., and Massetti, E. (2022) *Macro-Fiscal Implications of Adaptation to Climate Change*. https://www.imf.org/en/Publications/staff-climate-notes/Issues/2022/03/16/Macro-Fiscal-Implications-of-Adaptation-to-Climate-Change-512769

Aligishiev, Z., Ruane, C., and Sultanov, A. (2023) *User Manual for the DIGNAD Toolkit*. https://www.imf.org/en/Publications/TNM/Issues/2023/06/05/A-User-Manual-for-the-DIGNAD-Toolkit-531886

Ameli, N. et al. (2021) Higher Cost of Finance Exacerbates a Climate Investment Trap in Developing Economies. *Nat. Commun.* 12, Paper 4046.

Bassi, A. M., Bechauf, R., Casier, L., and Cutler, E. (2021) *How Can Investment in Nature Close the Infrastructure Gap? An Estimate of How Much Nature-Based Infrastructure Can Save Costs and Create Value Relative to Traditional Grey Infrastructure*. https://nbi.iisd.org/wp-content/uploads/2021/10/investment-in-nature-close-infrastructure-gap.pdf

Batten, S. (2018) *Climate Change and the Macro-Economy: A Critical Review*. SSRN. https://papers.ssrn.com/abstract=3104554

Battiston, S., Monasterolo, I., Riahi, K., and van Ruijven, B. J. (2021) Accounting for Finance Is Key for Climate Mitigation Pathways. *Science* 372, 918–920.

Bernhofen, M., Burke, M., Puranasamriddhi, A., Ranger, N., and Shrimali, G. (2024) *The Impact of Physical Climate Risks and Adaptation on Sovereign Credit Ratings*. SSRN. https://doi.org/10.2139/ssrn.4950708.

Bressan, G., Đuranović, A., Monasterolo, I., and Battiston, S. (2024) Asset-Level Assessment of Climate Physical Risk Matters for Adaptation Finance. *Nat. Commun.* 15, Paper 5371.

CDRI (2023) *Global Infrastructure Resilience—Capturing the Resilience Dividend*. Report. https://doi.org/10.59375/biennialreport.ed1

Dang, H.-A. H., Hallegatte, S., and Trinh, T.-A. (2024) *Does Global Warming Worsen Poverty and Inequality? An Updated Review*. IZA Discussion Paper 16570. https://www.ssrn.com/abstract=4622015

Dasgupta, P. (2024) *The Economics of Biodiversity: The Dasgupta Review*. Cambridge University Press.

Farmer, J. D., Hepburn, C., Mealy, P., and Teytelboym, A. (2015) A Third Wave in the Economics of Climate Change. *Environ. Resour. Econ.* 62, 329–357.

Hall J. W., Tran, M., Hickford, A. J., Nicholls, R. J. (eds.) (2016) *The Future of National Infrastructure: A System-of-Systems Approach*. Cambridge University Press. https://doi.org/10.1017/CBO9781107588745

Hall, J.W., Aerts, J. C. J. H., Ayyub, B. M., Hallegatte, S., Harvey, M., Hu, X., Koks, E. E., Lee, C., Liao, X., Mullan, M., Pant, R., Paszkowski, A., Rozenberg, J., Sheng, F., Stenek, V., Thacker, S., Väänänen, E., Vallejo, L., Veldkamp, T. I. E., van Vliet, M., Wada, Y., Ward, P., Watkins, G., and Zorn, C. (2019) *Adaptation of Infrastructure Systems: Background Paper for the Global Commission on Adaptation*. Environmental Change Institute, University of Oxford. https://gca.org/wp-content/uploads/2020/12/GCA-Infrastructure-background-paperV11-refs_0.pdf

Hallegatte, S., Rentschler, J., and Rozenberg, J. (2019) *Lifelines: The Resilient Infrastructure Opportunity*. World Bank, Washington, D.C. https://doi.org/10.1596/978-1-4648-1430-3

Hallegatte, S., Rentschler, J., and Rozenberg, J. (2020) *The Adaptation Principles*. World Bank, Washington, D.C.

Hepburn, C., and Farmer, J. D. (2020) Less Precision, More Truth: Uncertainty In Climate Economics And Macroprudential Policy. In: *Handbook on the Economics of Climate Change* (ed. G. Chichilnisky, and A.Rezai), pp. 420–438. Cheltenham: Edward Elgar Publishing.

High-Level Expert Group on Scaling Up Sustainable Finance in Low- and Middle-income Countries (2024) *High-Level Expert Group on Scaling up Sustainable Finance in Low- and Middle-Income Countries Mandated by the European Commission: Final Recommendations*. https://international-partnerships.ec.europa.eu/document/download/b5b4ed83-ff82-4684-b301-bf5e4dcd1f28_en?filename=hleg-final-recommendations-april-2024_en.pdf

IMF (2019) *Vanuatu: 2019 Article IV Consultation-Press Release; Staff Report; and Statement by the Executive Director for Vanuatu*. https://www.imf.org/en/Publications/CR/Issues/2019/06/12/Vanuatu-2019-Article-IV-Consultation-Press-Release-Staff-Report-and-Statement-by-the-46991

IMF (2022a) *Staff Guidance Note on the Sovereign Risk and Debt Sustainability Framework for Market Access Countries*. https://www.imf.org/en/Publications/Policy-Papers/Issues/2022/08/08/Staff-Guidance-Note-on-the-Sovereign-Risk-and-Debt-Sustainability-Framework-for-Market-521884

IMF (2022b) *Building Resilience to Natural Disasters and Climate Change: A Model Application to Timor Leste*. https://www.elibrary.imf.org/downloadpdf/journals/002/2022/308/article-A001-en.xml

Johnson, J. A., Ruta, G., Baldos, U., Cervigni, R., Chonabayashi, S., Corong, E., Gavryliuk, O., Gerber, J., Hertel, T., Nootenboom, C. and Polasky, S. (2021) *The Economic Case for Nature: A Global Earth-Economy Model to Assess Development Policy Pathways*. World Bank, Washington, D.C.

Kahn, M. E., Mohaddes, K., Ng, R. N., Pesaran, M. H., Raissi, M., and Yang, J. C. (2021) Long-Term Macroeconomic Effects of Climate Change: A Cross-Country Analysis. *Energy Econ.* 104, Paper 105624.

Klusak, P., Agarwala, M., Burke, M., Kraemer, M., and Mohaddes, K. (2023) Rising Temperatures, Falling Ratings: The Effect of Climate Change on Sovereign Creditworthiness. *Manag. Sci.* 69, 7468–7491.

Marotta, F., Ranger, N., and Fankhauser, S. (2023) *Securing Climate Compatible Growth: The Role of Fiscal Policy in Driving the Resilient Transition through Times of Crisis*.

Marto, R., Papageorgiou, C., and Klyuev, V. (2018) Building Resilience to Natural Disasters: An Application to Small Developing States. *J. Dev. Econ.* 135, 574–586.

Melina, G., and Santoro, M. (2021) *Enhancing Resilience to Climate Change in the Maldives*. https://www.imf.org/en/Publications/WP/Issues/2021/04/23/Enhancing-Resilience-to-Climate-Change-in-the-Maldives-50293

Monasterolo, I., Nieto, M., and Schets, E. (2023) *The Good, the Bad and the Hot House World: Conceptual Underpinnings of the NGFS Scenarios and Suggestions for Improvement*. Occasional Paper Series No. 2302. Banco de España. https://doi.org/10.2139/ssrn.4211384

Ranger N., Weidinger M., Bernhofen M., Burke M., Lambin R., Puranasamriddhi A., Sabuco J., and Spacey Martín, R. (2025) *Enabling Adaptation: Sustainable Fiscal Policies for Climate Resilient Development and Infrastructure*. Environmental Change Institute, University of Oxford and Green Fiscal Policy Network. https://www.eci.ox.ac.uk/sites/default/files/2025-01/UNEP%20Enabling%20Adaptation%20Report%20%282025%29.pdf

Ranger, N., Alvarez J., Freeman, A., Harwood, T., Obersteiner, M., Paulus, E. and Sabuco, J. (2023) *The Green Scorpion: The Macro-Criticality of Nature for Finance – Foundations for Scenario-Based Analysis Of Complex And Cascading Physical Nature-Related Risks*. Environmental Change Institute, University of Oxford. https://www.ngfs.net/sites/default/files/medias/documents/ngfs_occasional_paper_green-scorpion_macrocriticality_nature_for_finance.pdf

Ranger, N., Low, L. P., and Signer, B. L. (2021) *Financial Protection of Critical Infrastructure Services*. https://www.financialprotectionforum.org/publication/financial-protection-of-critical-infrastructure-services

Ranger, N., Mahul, O., and Monasterolo, I. (2022) *Assessing Financial Risks from Physical Climate Shocks: A Framework for Scenario Generation*. https://documents.worldbank.org/en/publication/documents-reports/documentdetail/760481644944260441/Assessing-Financial-Risks-from-Physical-Climate-Shocks-A-Framework-for-Scenario-Generation

Ranger, N., Oliver, T., Alvarez, J., Battiston, S., Bekker, S., Killick, H., Hurst, I., Liadze, I., Millard, S., Monasterolo, I., and Perring, M. (2024) *Assessing the Materiality of Nature-Related Financial Risks for the UK*. Green Finance Institute. https://oms-www.files.svdcdn.com/production/downloads/reports/GFI-GREENING-FINANCE-FOR-NATURE-FINAL-FULL-REPORT-RDS4.pdf

Rozenberg, J., and Fay, M. (2019) *Beyond the Gap: How Countries Can Afford the Infrastructure They Need While Protecting the Planet*. World Bank, Washington, D.C.

Sadler, A., Ranger, N., Fankhauser, S., Marotta, F., and O'Callaghan, B. (2024) The Impact of Covid-19 Fiscal Spending on Climate Change Adaptation and Resilience. *Nat. Sustain.* 7, 270–281.

Spacey Martín, R., and Ranger, N. (n.d.) The Impact of COVID-19 Fiscal Spending on Nature. Environmental Change Institute, University of Oxford. Unpublished Manuscript.

Spacey Martín, R., Ranger, N., and England, K. (2024) The (In)coherence of Adaptation Taxonomies. SSRN. https://doi.org/10.2139/ssrn.4874598.

Stern, N. (2016) Economics: Current Climate Models Are Grossly Misleading. *Nature* 530, 407–409.

Thacker, S. et al. (2021) *Infrastructure for Climate Action*. UNOPS. https://content.unops.org/publications/Infrastructure-for-climate-action_EN.pdf.

UNEP (2023) *Nature-Based Infrastructure: How Natural Infrastructure Solutions Can Address Sustainable Development Challenges and the Triple Planetary Crisis*. https://wedocs.unep.org/xmlui/handle/20.500.11822/44022

UNEP and University of Oxford (2024). *Introducing the Sustainable Budgeting Approach*. https://greenfiscalpolicy.org/introducing-the-unep-university-of-oxford-sustainable-budgeting-approach/

Volz, U., and Ranger, N. (2024) *Fiscal Risks and Debt Sustainability*.

Volz, U., Beirne, J., Ambrosio Preudhomme, N., Fenton, A., Mazzacurati, E., Renzhi, N. and Stampe, J. (2020) *Climate Change and Sovereign Risk*. Project Report. https://doi.org/10.25501/SOAS.00033524

Weikmans, R. (2023) *The Normative Foundations of International Climate Adaptation Finance*. Cambridge University Press.

Appendix. Comparison of climate-economy model types

	Dynamic Stochastic General Equilibrium (DSGE)	Computable General Equilibrium (CGE)	Stock Flow Consistent (SFC)	Process-based Integrated Assessment Models (IAMs)	Aggregated Integrated Assessment Models (IAMs)
Representation of the economy	Detailed Calibrated on sector data at country and regional levels. Market-clearing prices, representative agents with forward-looking expectations. Finance treated as exogenous frictions.	Varied Dynamic CGEs calibrated on granular sector data at country and regional levels. Market-clearing prices, representative agents with forward-looking expectations. No finance.	Detailed Dynamic balance sheet assessment with endogenous shocks. Heterogenous agents and adaptive expectations. Out-of-equilibrium dynamics. Financial agents and market, macro-financial feedback.	Aggregated Ramsey-style long-term economic growth model. Market clearing prices, representative agents. No finance.	Aggregated Ramsey-style long-term economic growth model. Market clearing prices, representative agents. No finance.
Representation of non-economic systems	No Some models might embed greenhouse gas emissions from production	No Some models might embed greenhouse gas emissions from production	Yes Agriculture, energy	Yes Agriculture, land-use, energy, water, and climate systems	Limited Climate system
Carbon price	Exogenous/ assumed	Exogenous/ assumed	Endogenously generated	Marginal Abatement Cost (MAC)	Social Cost of Carbon (SCC)
Use for cost-benefit analysis	No Used to build economic intuition	Yes	Yes Comparison of policy costs (socioeconomic, financial) and co-benefits	No Climate damages calculated separately	Yes
Geographic resolution	Global—Regional—Country	Regional—Country	Regional—Country	Global—Regional Country available through additional downscaling	Global-Regional
Explicit accounting for carbon budget	No	No	No	Yes	No
Sector granularity	Limited Energy sector	Yes Full sectoral disaggregation of the economy	Yes For high/low-carbon, labor/capital-intensive sectors in the economy	Yes Several energy-intensive sectors	No

Source: reproduced from Monasterolo et al. (2023)